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CR 94.006

OCEAN MODULE BARGE CONNECTION SYSTEMS DEVELOPMENT

An Investigation Conducted by:

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The study was to develop broad concepts to connect barge modules 40-ft long by 25-ft wide by 8-ft deep approximately 30 long tons weight. All the modules considered are to be lifted into the open sea and connected into larger barge assemblies suitable for transport of cargo and other tasks. It became evident at an early stage in the work that whilst a wide variety of concepts could be used to join modules together with relative simplicity, low technology and adequate strength, the assessments of sea-keeping and relative motion of the module result in the situation where the bringing together of the modules and safely locating them securely in the manner that will allow connection to take place, presents the greatest challenge and should command the greater portion of this work and of further investigation and development.

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OCEAN BARGE MODULAR CONNECTION SYSTEM DEVELOPMENT STUDY

Introduction

The study is to assess the task and develop broad concepts to connect barge modules 40’ long x 25’ wide x 8’ deep approximately 30 long tons weight. All the modules considered are to be lifted into the open sea and connected into larger barge assemblies suitable for transport of cargo and other tasks.

Overall quantitative assessments of the task and current available systems has been made. Of overriding importance, however, was the qualitative assessment of means of carrying out the task in a safe and practical manner.

CHAPTER 1

CHAPTER 1

Motion of Modules in a Seaway & Associated Aspects

A brief review of a variety of sources of data for both prediction of wave conditions and of the movement of bodies in waves was carried out. Attention was given to the conditions in which a 3’ significant wave height would be achieved rather than concentration on the broader definitions of a seastate. Clearly, waves of a height of approximately 3’ can be generated with a very wide variety of wave lengths from a long ocean swell anything up to 1,500 feet from crest to crest to wind generated shallow water tide assisted waves with the wave length down as short as 50’ - 60’ (See Table 1). It is self evident that waves of the longer wave lengths will have no appreciable effect on the joining of the modules in a seaway, the wave angle being so shallow as to not cause any significant relative motion between modules. The only possible effect would be a small degree of heave and surge relative to the carrying ship.

TABLE 1

Seastate Definitions
(Dimensions in feet)

Sea State Number	Significant Wave Height	Typical Wavelength (Swell)	Typical Wavelength (Wind Generated)
2	1 1/2 to 2 1/4	750 to 1125	15 to 40
3	3 to 4	1500 to 2250	30 to 70
4	6 to 7	3000 to 3500	60 to 90

The scenario deserving most consideration is the behaviour of modules relative to each other in the shorter wave length waves where significant relative motion between one module and the next will be experienced. In certain cases, operations may be required to be carried out in areas of relatively shallow water close to the coast, in estuaries etc. where wind generated waves influenced by the shore, tidal currents, the anchored carrying vessel etc. will inevitably produce short wave length steep seas. Limiting the operations envelope to conditions when only long ocean swells occur is too restrictive to be of use. The works commissioned by NCEL from East Port International (Contract N00123-84-D-0130 of 6 June 1986) and by Garrison (Contract N47408-93-C-7346 of September 1993) together with our consideration and assessments, indicate that in such conditions the relative motion of modules will be very significant.

From practical considerations, it is believed likely that in most cases the operator will have little choice but to attempt the joining of the modules with the longitudinal (40') axis effectively at right-angles to the oncoming waves. Unless a complex system of mooring is employed, then regardless of whether the carrying ship or first module is moored or anchored, it is likely that in most cases the unit will lie head to sea. In any event, although beam seas produced lower relative motions for end to end joining than head seas, it is difficult to maintain modules or carrying vessels in this attitude.

In the circumstances where such control could be exercised, then positioning of the carrying vessel to provide a lee in which to operate effectively overcomes the majority of difficulties of the afloat joining of modules. Considering that such stipulation would be too restrictive in operational terms, the study has continued to address methods that might be adopted and the motions likely to be encountered in the head sea short wave length condition.

Whilst different sources of data and differences in the basic assumptions yield slight differences in evaluations of pontoon to pontoon relative motions, it is clear that the relative movement at adjoining ends of two 40' modules in a 3' wave can be predicted to be between 4-1/2 - 5-1/2 feet with anticipated accelerations of 4-1/2 feet per second per second or 0.15g. The wave form and module positions is demonstrated in the Diagram Fig 1 and 2 and a numeric summary given in Table 2.

TABLE 2

Relative Motion at Joining Ends of 40ft modules in 3ft Wave 60ft Wavelength (approx.)
(Dimensions in feet above or below smooth water datum).

Single Module	On Crest	In Trough	2 Modules Relative
Heave at mid length	+1.2ft	-1.2ft	2.4ft
Pitch 4 1/2 degr.	+1.4ft	-1.4ft	2.8ft
Total Displacement	+2.6ft	-2.6ft	5.2ft

From Garrison predictions excluding mutual excitation or damping.

It is very clear that with this amount of relative motion then none of the present connector systems are capable of being operated and indeed on safety grounds, personnel working anywhere in the vicinity of the adjoining pontoon ends cannot be considered. Methods, therefore, have to be considered of bringing modules together securely from locations relatively remote from the joining position, albeit on the modules themselves, without the need to transfer personnel from one module to the other during the process and with sufficient precision to enable the joining process to be subsequently carried out securely and safely. Although relative motions between already joined groups of modules and further unjoined units will be reduced, they are still likely to be of a magnitude such that the same practicality and safety considerations will apply.

Wave length 65ft
Wave Height 3.5ft
Wave Type Trochoidal
Pontoon Size 40ft x 25ft x 8ft

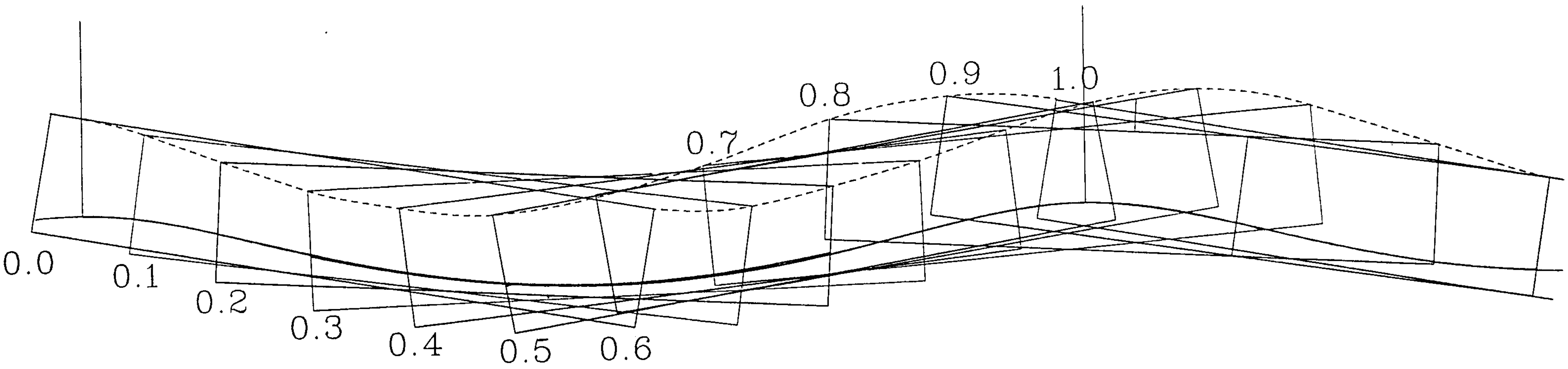


Figure 1

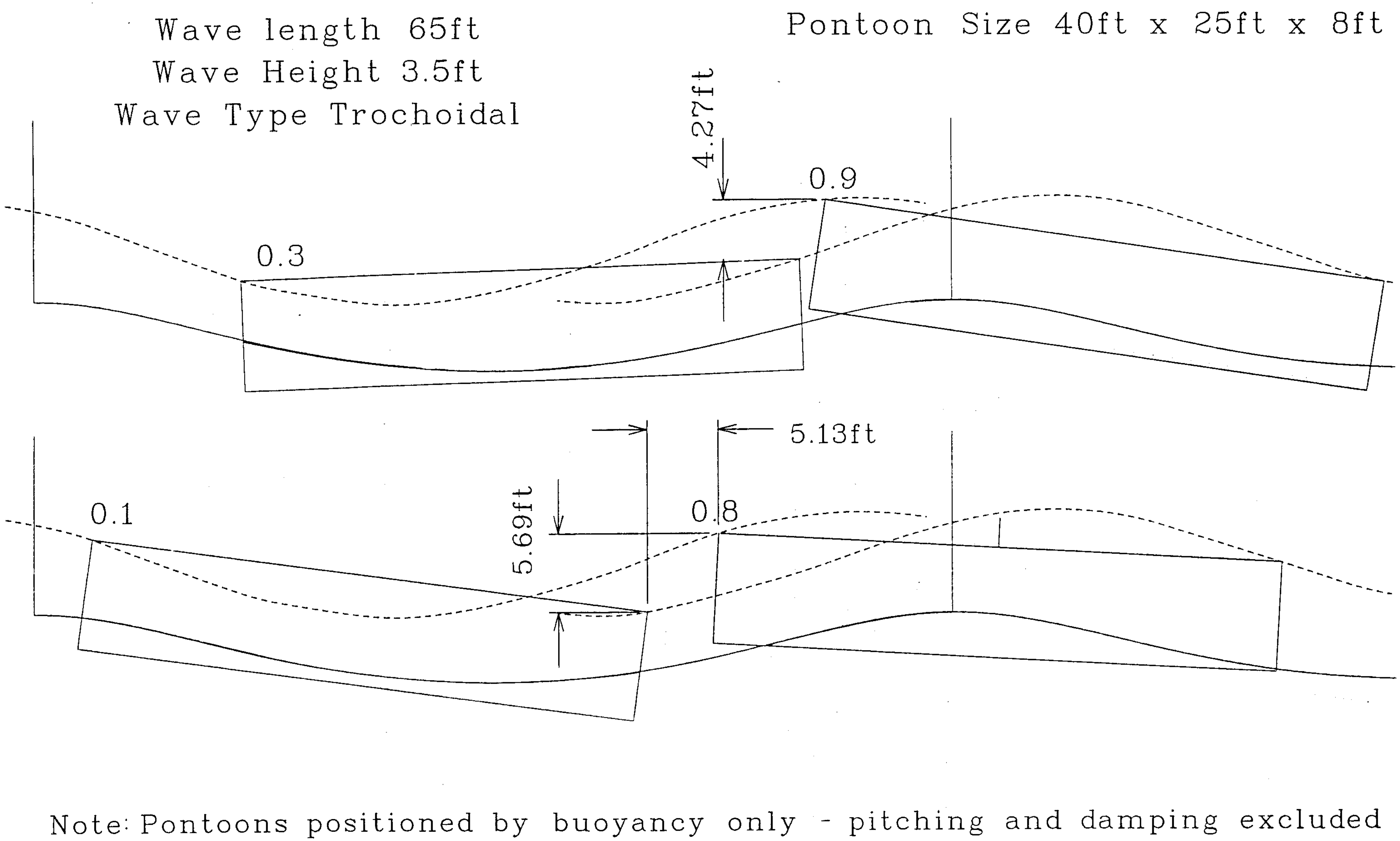

Wave length 65ft
Wave Height 3.5ft
Wave Type Trochoidal
Pontoon Size 40ft x 25ft x 8ft
4.27ft
0.9
0.3
5.13ft
5.69ft
0.1
0.8
Note: Pontoons positioned by buoyancy only - pitching and damping excluded

Figure 2

Existing Connector Systems

A detailed comparison of existing module systems and connecting methods which are commercially available is provided under the East Port International report of 6th June 1986 already referenced above. It is unnecessary to repeat all that work, however, there are a number of conclusions that can be drawn relative to possibilities of application to joining in a seaway.

Whilst each system has its own relative merits and demerits, and even though, for example the Flexeflote and Mexecell system are able to be successfully operated in other than completely smooth water, even excepting that the connector systems are either currently of sufficient strength or are capable of being provided to adequate strength to sustain the inter-modular loads both from motion in a seaway and embarked cargo once the modules are joined, no current system is capable of connecting modules at all, let alone in safety given the relative motion of the individual modules envisaged. It is concluded, therefore, that methods of bringing the modules together and locating them to enable connection to take place must be addressed and potential solutions identified before detailed analysis of connector systems becomes possible.

Fundamental to any connector system is the choice either of each module being fitted with some form of male and female devices, built into the module with a provision for locking these devices after the connection, or alternatively a system whereby universal facilities are provided on the modules and some form of connector link is arranged to achieve the connection. Clearly, with the degree of movement contemplated between modules during assembly in a seaway then arrangements of male/female devices with any form of projection on the modules is likely to prove impractical in operation and extremely prone to damage both of the connector systems and the modules.

Load Assessments

This section describes in brief the development of the preliminary load envelope to be used in consideration of connector designs. The aim is to:

- identify load cases relevant to perceived operation;
- quantify the shear and bending loads implied by these cases;
- extract the worst cases to establish a connector load envelope.

Details of how the modules will be employed are of course not known at present However, it is understood that:

- transport will be via container ships;
- offload at the operations area will be module by module, using shipboard cranes;
- assembly and operation will be necessary in sea states up to and including 3;
- survival of the assembled raft in sea state 5 is required;
- ISO containers will be transported on assembled rafts, and manipulated using the Rough Terrain Container Handler;
- on-deck transport of tanks may be necessary.

Since offload at the operational area is to be module by module, the requirements of storage, transport and disembarkation are not relevant to the connector system design, except in so far as designs must not obstruct transport and handling using container facilities. Loads arising from these considerations and from connector installation will depend on the form of the connectors - loads on the modules are not our concern at present - and so will have to be addressed separately later in the project, when ideas for connectors are presented.

The main load sources relevant to basic considerations of the connector system are, therefore:

- Wave Loads
- Deck-cargo loads.

Wave loads: no deck cargo

Operation in sea state 3 has been examined to some extent by Garrison (contract N47408-93-C-7346, report 110-93, Sept. 1993), considering both individual modules and assembled rafts in a seaway. These studies include no allowance for deck cargo, however. For the unloaded state, the figures given below can be extracted from this report.

For TWO connected modules:

sea state	wave heading (deg)	forces (kip) fx	fy	fx	Moments (kip ft) mx	my	mz
2.5	0	2.1	4	0	0	0	230
2.5	15	2	3.7	0.46	25	16	220
2.5	30	1.9	3	0.8	47	35	190
2.5	45	1.7	2	0.98	65	59	150
2.5	60	1.4	0.99	1.4	72	90	98
2.5	75	0.79	0.23	2.4	58	140	34
2.5	90	0.19	0.19	2.8	15	170	5.4
3	0	2.1	3.9	0	0	0	240
3	15	2.05	3.6	0.45	25	18	230
3	30	1.92	2.8	0.78	48	38	200
3	45	1.71	1.9	0.95	65	62	153
3	60	1.36	0.9	1.28	70	92	94
3	75	0.74	0.21	2.2	55	133	32
3	90	0.18	0.11	2.6	13.4	160	5.1

a wave heading of 0 deg. is a head sea; 90 deg. represents a beam sea.

For THREE connected modules, only the vertical bending moment, Mz, is given (as this component dominates):

sea state	wave heading (deg)		(kip ft.)
2.5	0 (head seas)	significant	508
2.5	30	significant	464
2.5	0 (head seas)	maximum	1046
2.5	30	maximum	928
5	0 (head seas)	significant	1070
5	30	significant	896
5	0 (head seas)	maximum	2140
5	30	maximum	1792

To get some idea of the likely forces being transmitted through the connectors, these loads have been processed assuming one connector 10 feet either side of the module centreline, with connections near the top and bottom of the modules; a vertical lever of 7 feet has been used. Thus two adjacent modules would be pinned together at four points on their mating faces. Using these assumptions, the derived longitudinal and vertical connector-pin forces* are:-

* = transverse forces are not included, as these are relatively small.

Two modules, sea state 2.5:

Wave heading (deg)	Longitudinal Forces (kips) From Fx	From My	From Mz	Total	Vertical Forces (kips) From Fy	From MX	Total
0	0.5	0.0	16.4	17.0	2	0	2.0
15	0.5	0.4	15.7	16.6	1.85	1.25	3.1
30	0.5	0.9	13.6	14.9	1.5	2.35	3.9
45	0.4	1.5	10.7	12.6	1	3.23	4.3
60	0.4	2.3	7.0	9.6	0.495	3.6	4.1
75	0.2	3.5	2.4	6.1	0.115	2.9	3.0
90	0.0	4.3	0.4	4.7	0.095	0.75	0.8

Two modules, sea state 3:

Wave heading (deg)	Longitudinal Forces (kips) From Fx	From My	From Mz	Total	Vertical Forces (kips) From Fy	From MX	Total
0	0.5	0.0	17.1	17.7	1.95	0	2.0
15	0.5	0.5	16.4	17.4	1.8	1.25	3.1
30	0.5	1.0	14.3	15.7	1.4	2.4	3.8
45	0.4	1.6	10.9	12.9	0.95	3.25	4.2
60	0.3	2.3	6.7	9.4	0.455	3.5	4.0
75	0.2	3.3	2.3	5.8	0.105	2.75	2.9
90	0.0	4.0	0.4	4.4	0.055	0.67	0.7

Three modules, sea state 2.5:

Wave heading (deg)	Longitudinal Forces (kips) From Fx	From My	From Mz	Total	Vertical Forces (kips) From Fy	From MX	Total
0	-	-	sig 36.3	36.3	-	-	-
30	-	-	sig 33.1	33.1	-	-	-
0	-	-	max 72.6	72.6	-	-	-
30	-	-	max 66.3	66.3	-	-	-

Three modules, sea state 5:

Wave heading (deg)	Longitudinal Forces (kips) From Fx	From My	From Mz	Total	Vertical Forces (kips) From Fy	From MX	Total
0	-	-	sig 76.4	76.4	-	-	-
30	-	-	sig 64.0	64.0	-	-	-
0	-	-	max 152.9	152.9	-	-	-
30	-	-	max 128.0	128.0	-	-	-

Note that this exercise is intended only to get a feel for the likely magnitude of the connector forces; it is not intended that the study be limited to a particular connector configuration.

The size of these point loads is not unreasonable; it is considered that connectors may be developed to handle loads of this magnitude.

Deck cargo loads

To quantify likely loads arising from the transport of deck cargoes, a simple static wave approach has been used. Here, a box-shaped barge, with loading symmetrical about midships (i.e. with no trim) was considered on a sinusoidal wave. The deck cargoes considered were:

- RTCH
- RTCH carrying container
- M1A1 tank
- 20 ft and 40 ft ISO containers

All these calculations used a double amplitude wave height of 3 feet, approximating sea state 3.

Table A and B presents the results of this study. Figures are presented for both 120 foot and 60 foot waves. Waves of 120 ft length are outside the main regime of sea state 3: with a significant wave height of 3.3 ft an average wave length of 59 feet applies. However, the 120 ft wave forms the extreme case for longitudinal bending of the raft.

Both the loads at the connector positions (i.e. at L/3 and 2L/3) and the maximum occurring anywhere in the raft are given: the latter are not directly relevant to this study but may be of use later in the project.

It can be seen from Table A and B that the maximum connector loads found were as follows:-

	120 ft wave	60 ft wave
maximum shear force	108 kip	109 kip
maximum hogging moment	3505 kip ft	2521 kip ft
maximum sagging moment	3263 kip ft	2279 kip ft

Comments on loading

The preceding sections estimate connector loads in operation, arising from waves and cargoes.

These may be summarised thus:

- For the unloaded condition, the worst moments occur in the survival state (sea state 5) and may reach c.2140 kip ft. Shear forces for this case are not given by Garrison, however, the maximum is unlikely to exceed the weight of a single module, i.e. about 77 kip.
- From the deck loadings considered, the maximum bending moments are around 3500 kip ft for a 120 ft long wave and 2500 kip ft for a 60 ft wavelength, at the connector positions. The maximum connector position shear force is around 108-109 kips for both wave lengths. The 60 foot wave length is the more realistic for sea state 3 operation.

Based on these figures, the suggested loading envelope for initial studies is:

bending moment capacity	2500 kip ft
shear force capacity	110 kip ft

These are the total loads at the section containing the connectors, rather than the loads in individual connectors. Considerations of handling (including system disembarkation) and of lateral and torque loading will be applied as design concepts evolve.

TABLE A

Static wave bending: 120 ft raft with deck cargoes
(sinusoidal waves)
Results are sorted by connector bending moment (hog positive)

120 ft wavelength; h = 3 ft

Case		at connectors SF (kip)	at connectors BM (kip)	maximum on raft SF (kip)	maximum on raft BM (kip)
20 ft cells at end	hog	85.6	3505	124.5	4404
40 ft cells at end	hog	108.4	3034	124.5	4164
20 ft cells over all	hog	39.9	1303	46.1	1745
20 ft cells at end	sag	5.8	899	43.4	921
RTCH (transport)	hog	2.5	546	36.7	554
Single M1A1	hog	2.5	461	42.5	462
40 ft cells at end	sag	28.7	428	36.8	674
3x20 ft cells midships	hog	5.3	405	26.7	417
RTCH + load	hog	14.8	216	59.2	-457
6x20 ft cells midships	hog	50	-495	56.8	-1077
6x40 ft cells midships	hog	5.8	-658	36.8	-679
Selfweight only	sag	36.6	-1237	43.6	-1623
20 ft cells over all	sag	39.9	-1303	46.1	-1745
RTCH (transport)	sag	77.2	-2059	77.8	-3273
Single M1A1	sag	81.5	-2145	81.6	-3446
3x20 ft cells midships	sag	84.2	-2202	84.3	-3358
RTCH + load	sag	93.8	-2394	94.4	-3948
6x20 ft cells midships	sag	129	-3101	131.4	-4568
6x40 ft cells midships	sag	85.6	-3263	124.5	-4165

TABLE B

Static wave bending: 120 ft raft with deck cargoes
(sinusoidal waves)
Results are sorted by connector bending moment (hog positive)

60 ft wavelength; h = 3 ft

Case		at connectors SF (kip)	at connectors BM (kip)	maximum on raft SF (kip)	maximum on raft BM (kip)
====		====	====	====	====
20 ft cells at end	sag	26.9	2521	102.8	2662
40 ft cells at end	sag	49.8	2049	67.5	2419
20 ft cells at end	hog	64.5	1884	67.5	2661
40 ft cells at end	hog	87.3	1412	94.4	2419
20 ft cells over all	hog	19.3	325	22.2	-431
20 ft cells over all	sag	19.3	325	22.2	431
RTCH (transport)	sag	57	-438	67.4	-1528
Single M1A1	sag	61.3	-524	72.6	-1701
3x20 ft cells midships	sag	64	-581	75.9	-1613
RTCH + load	sag	73.6	-773	87.4	-2203
RTCH (transport)	hog	18.5	-1075	39.2	-1528
Single M1A1	hog	22.8	-1161	43	-1701
3x20 ft cells midships	hog	25.6	-1218	42.3	-1613
RTCH + load	hog	35	-1410	59.7	-2203
6x20 ft cells midships	sag	108.8	-1479	116.3	-2823
6x40 ft cells midships	sag	64.5	-1642	67.5	-2419
6x40 ft cells midships	hog	70.2	-2116	67.5	-2823
6x40 ft cells midships	hog	26.9	-2279	94.3	-2420

CHAPTER 2

CHAPTER 2

JOINING OF MODULES IN A SEAWAY

ALIGNMENT & CONNECTION

As shown by Garrison, with modules of 40 ft length head to sea the relative motion of the modules is significant. The phases of the joining exercise, therefore, become:

- connecting the modules together whilst at a safe distance apart.
- drawing the modules together.
- restraining the relative motion of the modules.
- making the operational close coupled connection at top and bottom at various points on the joining face of the modules.

This will always apply, although the relative motion may be very significantly reduced by holding the modules with the seas on the beam, thus making the end-to-end connections with both modules rolling in phase. The same principle can be applied for side-to-side joining by placing modules side-by-side but head-to-sea.

Even ignoring other considerations, if the equipment used to bring the pontoons together and make the connection is too heavy, then not only do significant difficulties present themselves in terms of handling the equipment, but perhaps most importantly, the further complication arises of trying to join modules which are floating at different draughts.

From consideration of strength alone, it is considered that current connection systems can be made adequately strong to take joining and operating loads. However, with the large modules now being considered and their greater depths, such connector designs are likely to be on or beyond the borderline of what can be manhandled.

The potential relative motions and forces when bringing the pontoons together effectively preclude any arrangement which involved projections on the joining faces of the pontoons.

Bringing together and connecting, therefore, has to be done using arrangements which either involve recesses in the module faces, or operate essentially separately from the face.

Given that there will be many times during operations of the modules where motions of adjacent modules are not coincident, any form of fixed fendering on the pontoons, other than a complete fender face, may become an unacceptable projection.

It is conceptually possible to devise a connector which brings the modules together and also gradually locates them, providing an alignment tool, a buffer between the two modules and a connection mechanism. Needless to say, there are a number of drawbacks to such an arrangement, including size, difficulty of handling, the ability to make a rigid joint, complex module structure etc.

At this stage, it is not clear whether any type of ISO corner fittings are likely on modules of this size. Clearly from damage considerations with the modules floating together, a radius - albeit fairly small - to all corners and edges would seem to be very important. Local strength and the ability to absorb wear and damage must be catered for in all parts of the modules, not just the deck and connector points.

For safety considerations, we have assumed that until such time as the modules are securely brought together, if not finally operationally connected, then human operators on each module must remain a safe distance away from the joining edges of the modules.

With these various thoughts in mind, although many variations are possible, there appear to be two basic paths down which to progress. The first is to use the best technology available for basic seamanship techniques to reduce the motion as much as possible and then simply winch the modules together, hold them under tension and connect them. The second is to devise discreet machines, mechanisms or jigs to effectively establish a floating joining facility. The former approach will be the more adaptable as in general the more complex the arrangement, the more specific it will become to a particular module size, type and orientation. In addition, of course, there are logistic, man-power and cost considerations.

ASPECTS OF CONNECTION

The fixing of modules to one another in an operational configuration can take one of two basic forms: rigid or flexible. There is a certain natural tendency to view the rigid form as the more desirable, though each has its merits. Some pros and cons of the two approaches are summarised in table 3.1.

Rigid interconnection

As noted under “Alignment & Connection”, if modules can be brought together and held together with minimal relative motion, current connector principles (e.g. dog-bone, NA type) can be used to make rigid connections. Some alternatives may be desirable however.

Given that a rigid connection is to be made, the main components which such connections must be capable of resisting are axial tension and compression loads, vertical shear force and bending moments. Of these, the shear and bending loads tend to predominate; in any event, a connection capable of resisting a bending moment will generally also resist axial loads.

Efficient resistance of a vertical bending moment requires that the connections between modules be made at the deck and bottom of the modules, to gain the maximum lever arm. This also has benefits for the pontoon structure, as the loads induced coincide with the deck and bottom plate of the pontoon.

As noted under “Alignment & Connection”, projections from the pontoons are undesirable given the possible relative motions in this application. Rigid connection at top and bottom thus requires one of the following (see figure 3.1):

A. connections are made from the deck via a drop-in connector unit which makes the top and bottom joints (as in the dog-bone and NA systems);

B. the lower connection is made by extending something from the pontoon once the relative motions are restrained, via a mechanism operated from the deck or from within the pontoon;

C. the modules are pulled together with sufficient force to overcome any tensile forces arising from the bending moment, effectively producing a pretensioned beam.

D. the connection mechanism is contained in a separate module which provides both facilities for both location and connection of modules.

Each of these has benefits and disadvantages, some of which are summarised in table 3.2

Flexible interconnection

Flexible connections do not resist bending moments, thus removing the necessity for a bottom connection, and this is one of their major advantages: all operations can take place near deck level.

The lower portions of the modules need to be shaped, however, to avoid impact between modules, and this complicates their use with ISO facilities which are designed around the idea of standardised rectangular boxes. It is also necessary to provide sliding cover plates at the deck for safe operation in a seaway, and some restrictions are placed on the location of deck cargo such as freight containers, pontoons etc. which will be damaged if placed over a flexing joint. If such cargoes, with length of 40 feet or greater, are to be carried on deck then flexing would require their careful placement.

CONCEPTS

Concept range

A range of concepts have been included here. These are all considered workable, and range from basic seamanship methods to the creation of very specialised equipment. Rather than attempt verbal explanation of the concepts, they have been presented in sketch form in figures 4.1 (Note that no figure is included for the “floating dock” concept; this is similar in principle to the “SWATH docking station”). One sheet is included for each concept, for ease of comparison. The order of presentation of the different concepts is not significant, and the concept names have been chosen more for being memorable than for their engineering accuracy.

TABLE 3.1

Pros and cons of rigid & flexible connections

	PRO	CON
rigid connections	steadier working platform cargo can be placed anywhere on deck assembly can be lifted as a whole	modules must resist wave bending moments concentrated loads transmitted to modules
flexiblo connections	all connections close to deck no bending moment capacity needed lighter connections	cover plates needed at gaps careful placing of containers needed on deck raked module ends necessary connecors must withstand rubbing due to motion

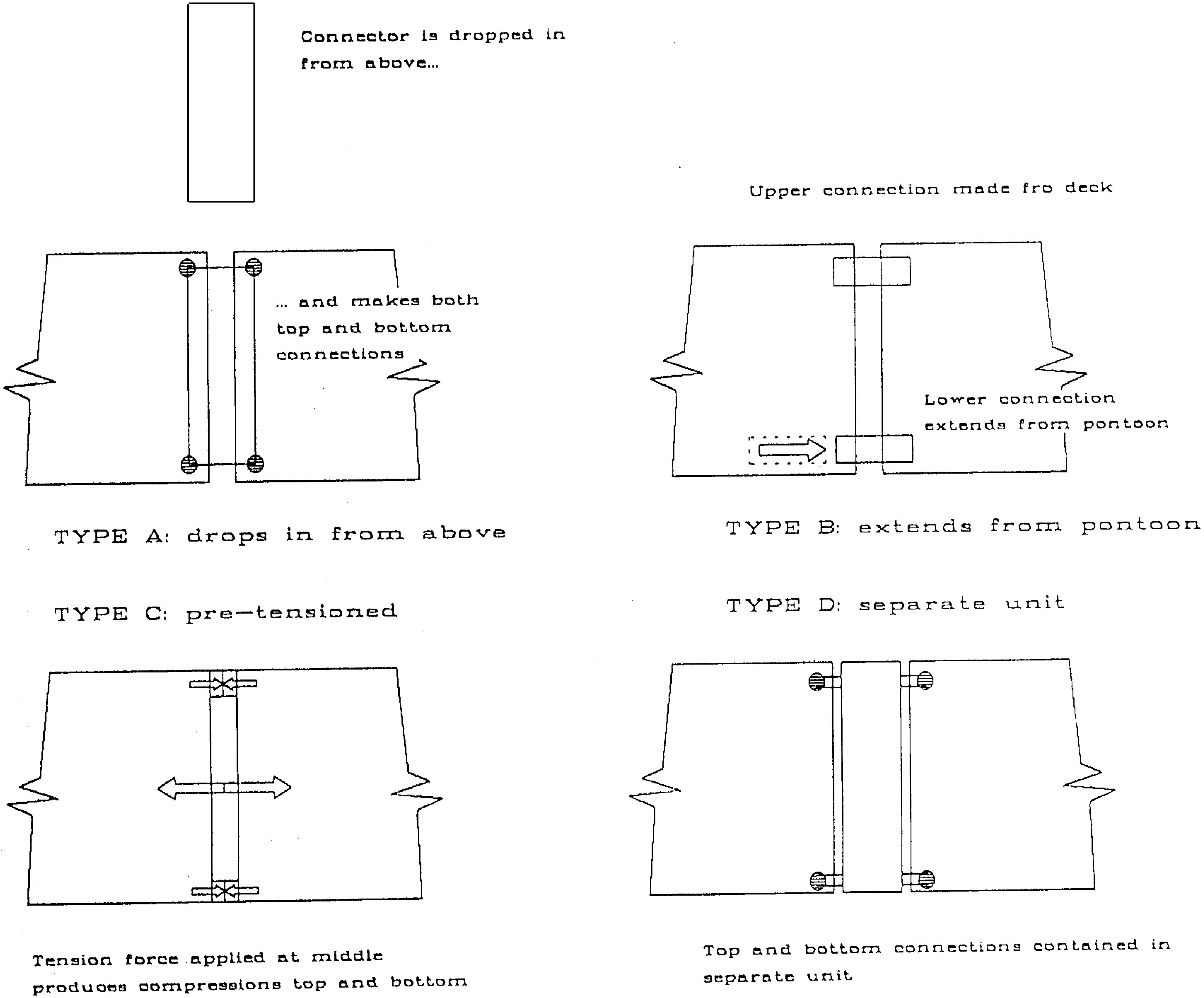


FIGURE 3.1
Possible connection schemes

TABLE 3.2
Rigid connectors for resistance of bending moment

A	DROP–IN UNIT
PRO	**CON**
simplicity	large weight to position separate item

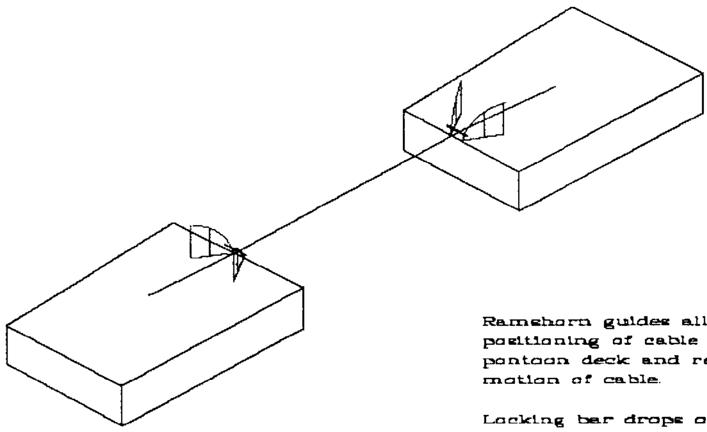
B	PRETENSIONING
PRO	**CON**
simplicity combines with alignment process large beraing area – distributes compressive loads	induces additional loads in pontoon requires tensile load applied within pontoon

C	EXTENDS FROM MODULE
PRO	**CON**
integrated	requires mechanism in module difficult to maintain

D	SEPARATE UNIT
PRO	**CON**
simpler pontoon combines with alignment tool	large and complex separate unit

FIGURE 4.1

Concept: alignment	name: Ramshorn



Ramshorn guides allow easy positioning of cable from pontoon deck and restrain motion of cable.

Locking bar drops over cable to restrain vertical movement.

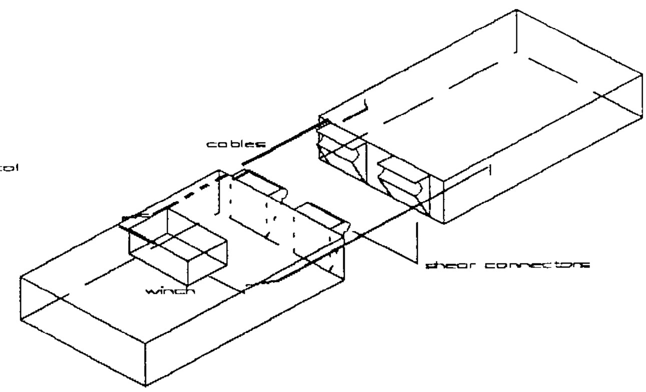
Winch (powered or hand) used to wind in cable and pull modules together.

safety in use	4	deck openings	5
hazard if fails	1	protrusions	5
reliability	4	configuration scope	5
cost	5	pontoon implications	5
ease of handling	3	Abilities as a connector:	
special equt. needed	4	maintainability	0
implicit strength	3	reliability	0
complexity	4	ease of repair	0
weight	4	speed	0
robustness	4	cost	0
no. of parts	5	structural efficiency	0
other equt needed	4	complexity	0
damage tolerance	4	deck obstruction	0

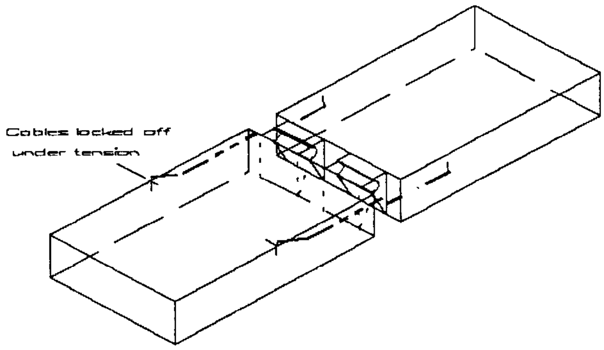
Concept: alignment connection	name: HUPOZOMA

Hupozoma

(tensioned rope running round the hull of a classical Greek warship)



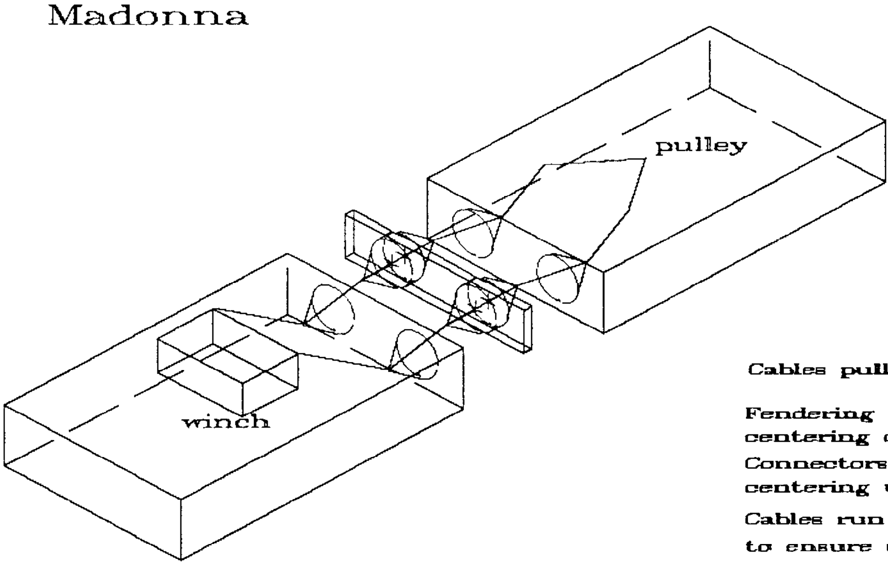
Cables are used to pull units together and to retain units in contact.



safety in use	4	deck openings	5
hazard if fails	1	protrusions	1
reliability	4	configuration scope	2
cost	5	pontoon implications	3
ease of handling	3	Abilities as a connector:	
special equt. needed	4	maintainability	4
implicit strength	3	reliability	3
complexity	4	ease of repair	2
weight	4	speed	4
robustness	4	cost	5
no. of parts	5	structural efficiency	2
other equt needed	4	complexity	4
damage tolerance	4	deck obstruction	5

Concept: alignment connection	name: Madonna

Madonna



Cables pull assembly together.

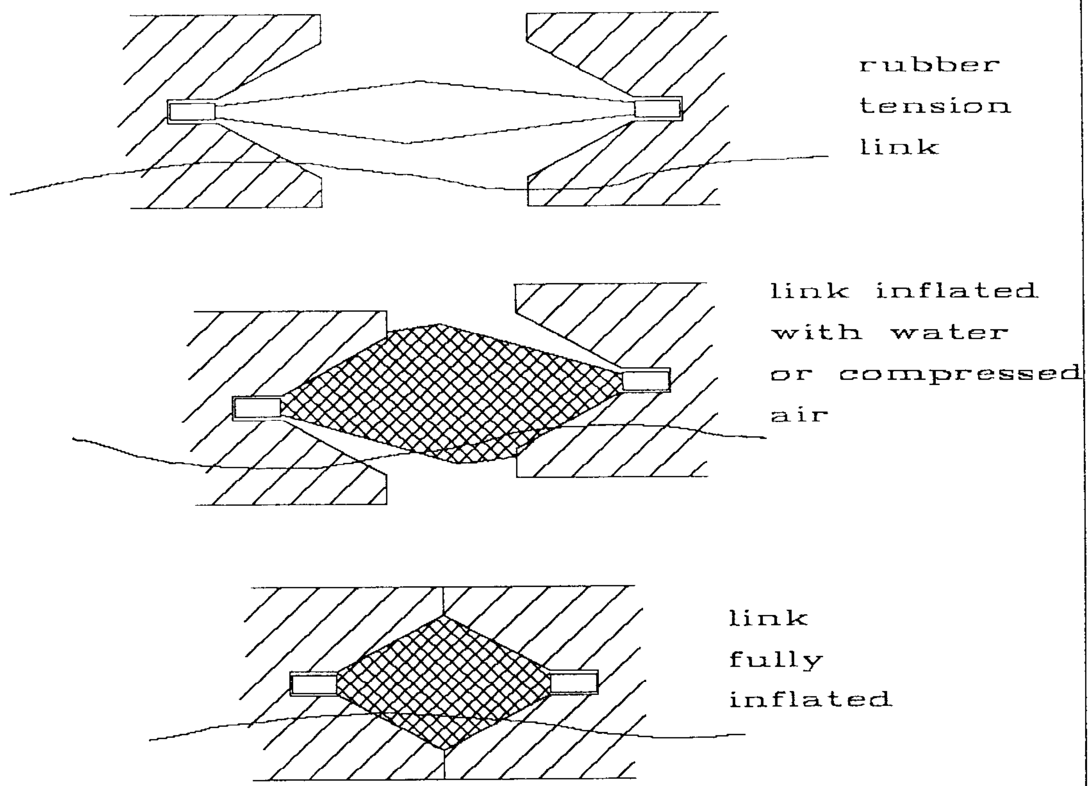
Fendering incorporated in centering cones.

Connectors incorporated in centering unit.

Cables run through cones, to ensure self-centering.

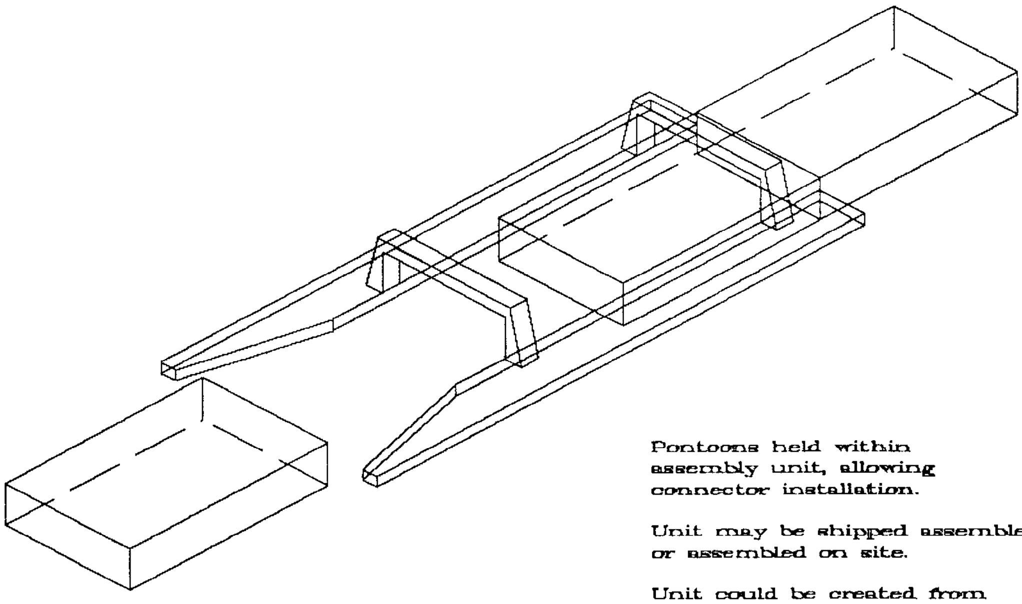
safety	in use	4	deck openings	4
	hazard if fails	4	protrusions	5
reliability		4	configuration scope	3
cost		4	pontoon implications	2
ease of handling		3	**Abilities as a connector:**	
special equt. needed		3	maintainability	3
implicit strength		5	reliability	5
complexity		3	ease of repair	4
weight		3	speed	5
robustness		5	cost	3
no. of parts		4	structural efficiency	5
other equt needed		3	complexity	3
damage tolerance		2	deck obstruction	5

Concept: alignment connection	name: Inflatable Link



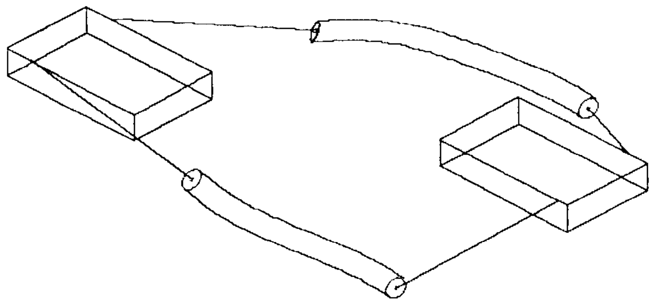
safety in use	4	deck openings	4
hazard if fails	4	protrusions	5
reliability	3	configuration scope	4
cost	3	pontoon implications	2
ease of handling	4	Abilities as a connector:	
special equt. needed	4	maintainability	2
implicit strength	4	reliability	3
complexity	3	ease of repair	2
weight	3	speed	3
robustness	4	cost	3
no. of parts	4	structural efficiency	3
other equt needed	4	complexity	3
damage tolerance	4	deck obstruction	5

Concept: alignment	name: Floating tramlines

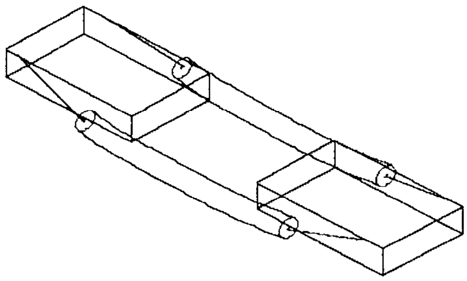


safety in use	5	deck openings	5
hazard if fails	2	protrusions	5
reliability	5	configuration scope	0
cost	4	pontoon implications	4
ease of handling	4	Abilities as a connector:	
special equt. needed	3	maintainability	0
implicit strength	0	reliability	0
complexity	3	ease of repair	0
weight	4	speed	0
robustness	4	cost	0
no. of parts	3	structural efficiency	0
other equt needed	2	complexity	0
damage tolerance	4	deck obstruction	0

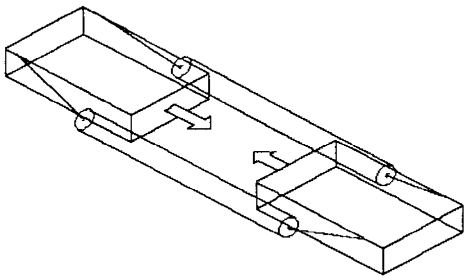
Concept: alignment	name: Pressurised tubes



Lines from floating tubes brought abord



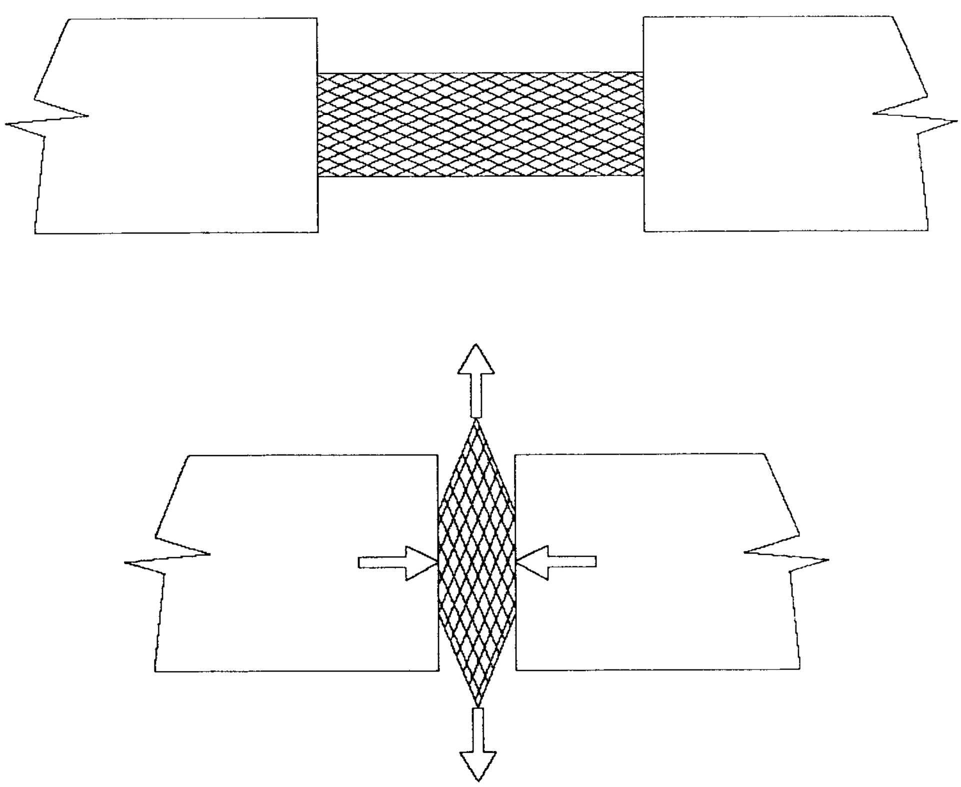
Lines used to bring tubes alongside; inflation of tubes begins.



Tubes are inflated.
Purchase on stiffened tubes used to bring pontoons together in alignment.

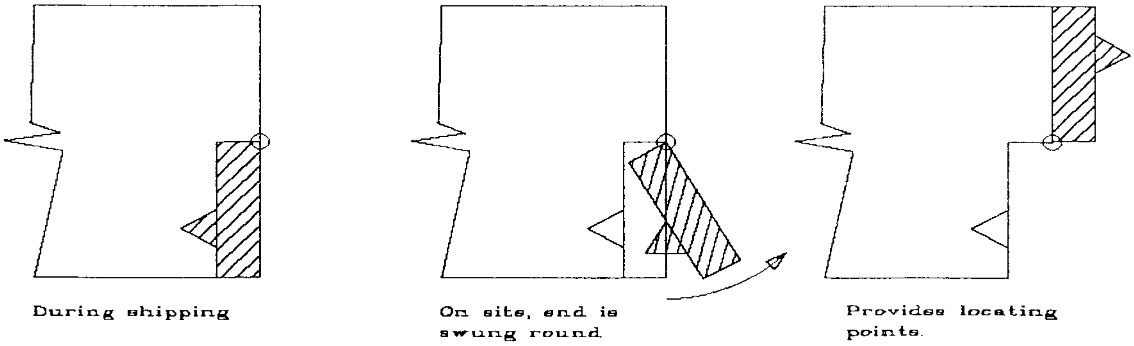
safety in use	4	deck openings	5
hazard if fails	3	protrusions	5
reliability	3	configuration scope	4
cost	3	pontoon implications	5
ease of handling	3	**Abilities as a connector:**	
special equt. needed	3	maintainability	0
implicit strength	0	reliability	0
complexity	3	ease of repair	0
weight	4	speed	0
robustness	3	cost	0
no. of parts	3	structural efficiency	0
other equt needed	3	complexity	0
damage tolerance	2	deck obstruction	0

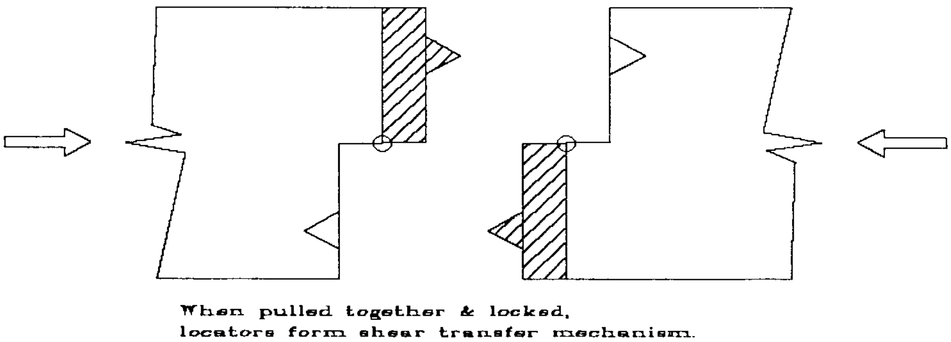
Concept: alignment	name: Bias Net



safety in use	3	deck openings	5
hazard if fails	2	protrusions	5
reliability	3	configuration scope	5
cost	5	pontoon implications	5
ease of handling	3	Abilities as a connector:	
special equt. needed	5	maintainability	0
implicit strength	0	reliability	0
complexity	4	ease of repair	0
weight	5	speed	0
robustness	4	cost	0
no. of parts	5	structural efficiency	0
other equt needed	5	complexity	0
damage tolerance	3	deck obstruction	0

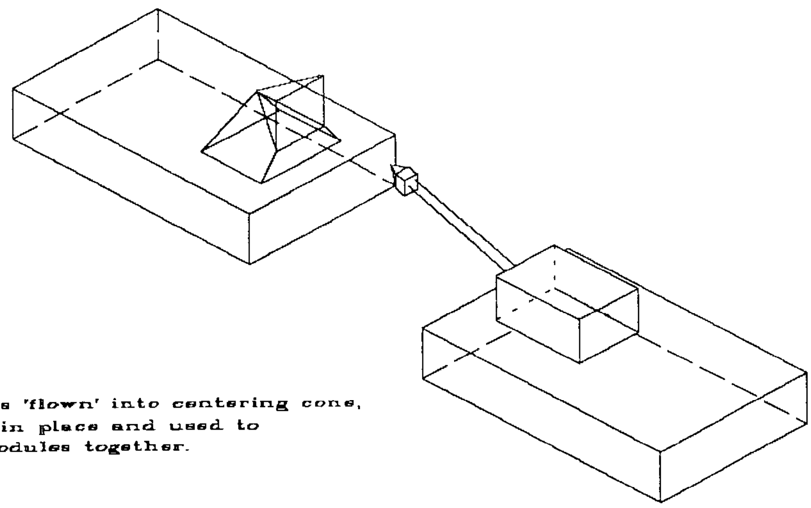
Concept: alignment connection	name: Folding Ends





safety in use	4	deck openings	5
hazard if fails	1	protrusions	3
reliability	4	configuration scope	2
cost	3	pontoon implications	2
ease of handling	3	Abilities as a connector:	
special equt. needed	4	maintainability	3
implicit strength	5	reliability	4
complexity	3	ease of repair	2
weight	3	speed	4
robustness	4	cost	4
no. of parts	4	structural efficiency	3
other equt needed	4	complexity	3
damage tolerance	3	deck obstruction	5

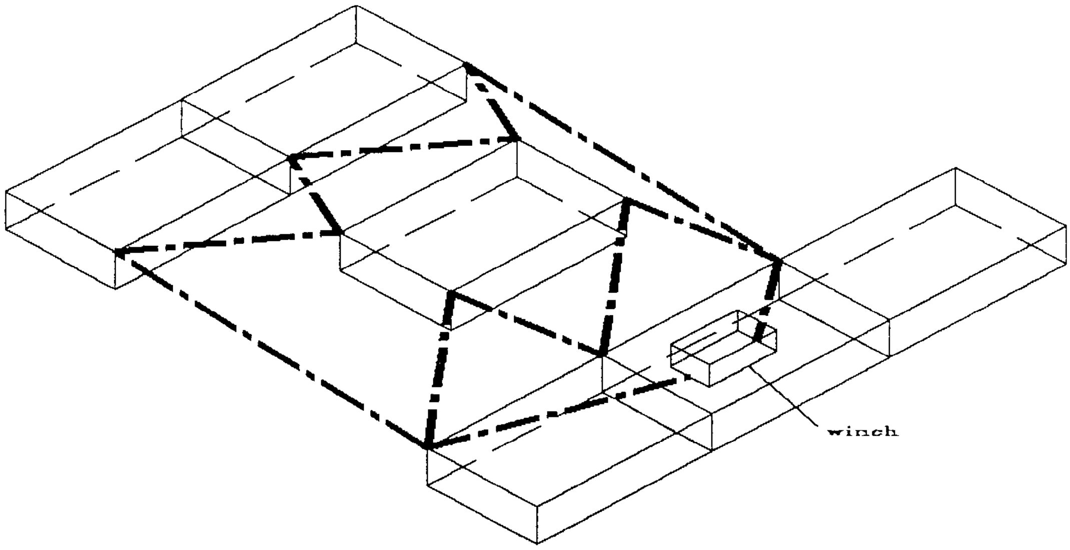
Concept: alignment	name: Powered Proboscis



Probe is 'flown' into centering cone, locked in place and used to pull modules together.

safety in use	5	deck openings	5
hazard if fails	4	protrusions	5
reliability	3	configuration scope	5
cost	2	pontoon implications	5
ease of handling	3	**Abilities as a connector:**	
special equt. needed	2	maintainability	0
implicit strength	0	reliability	0
complexity	2	ease of repair	0
weight	2	speed	0
robustness	3	cost	0
no. of parts	3	structural efficiency	0
other equt needed	3	complexity	0
damage tolerance	2	deck obstruction	0

Concept: alignment	name: Cat's Cradle

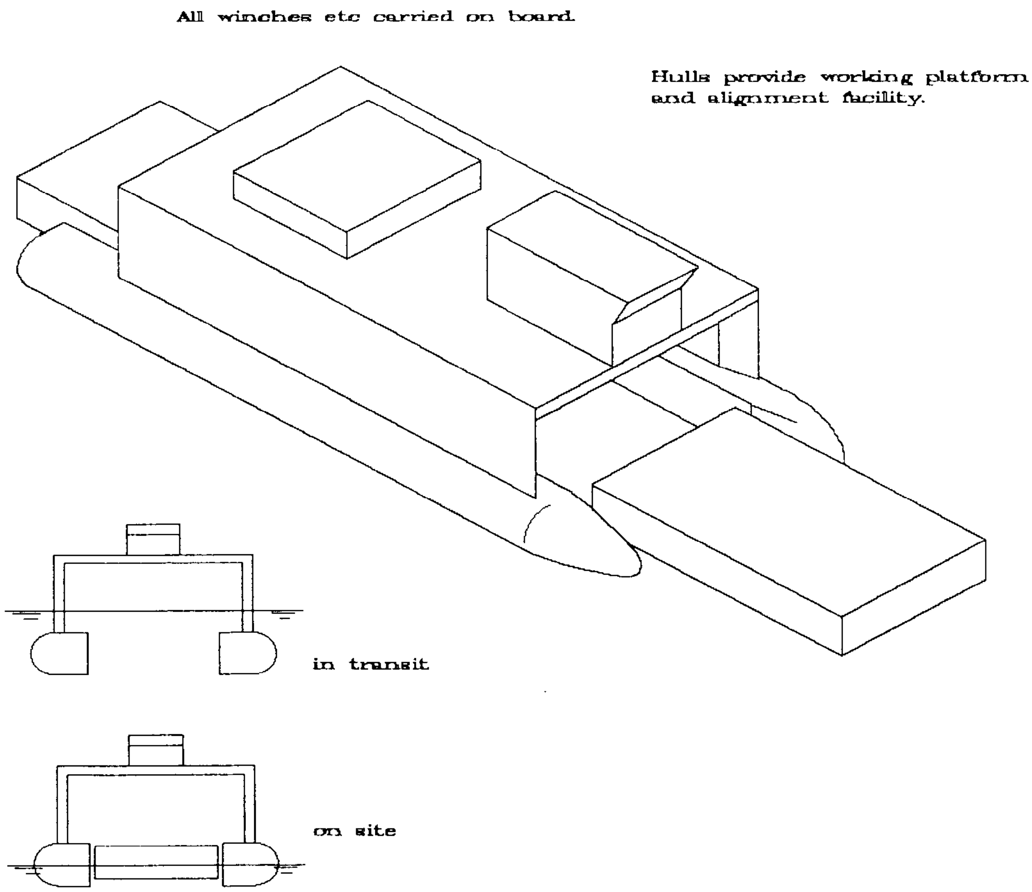


Cable is reeved through blocks;
tensioning cable brings
modules together.

Note that this arrangement is schematic only.

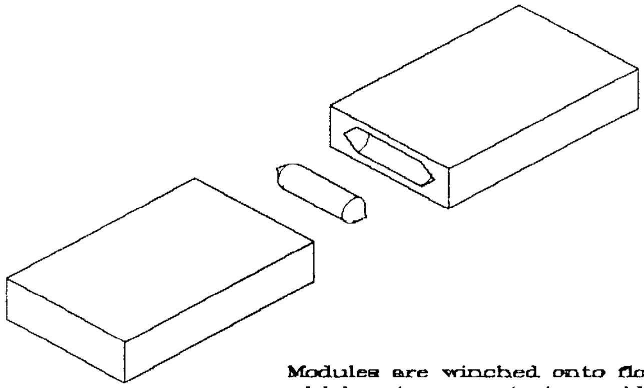
safety in use	1	deck openings	5
hazard if fails	3	protrusions	5
reliability	4	configuration scope	5
cost	5	pontoon implications	5
ease of handling	2	Abilities as a connector:	
special equt. needed	3	maintainability	0
implicit strength	0	reliability	0
complexity	4	ease of repair	0
weight	4	speed	0
robustness	4	cost	0
no. of parts	3	structural efficiency	0
other equt needed	4	complexity	0
damage tolerance	3	deck obstruction	0

Concept: alignment	name: SWATH Docking Station

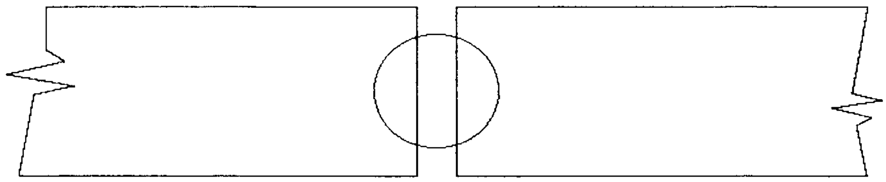


safety in use	5	deck openings	5
hazard if fails	0	protrusions	5
reliability	3	configuration scope	0
cost	0	pontoon implications	5
ease of handling	5	**Abilities as a connector:**	
special equt. needed	5	maintainability	0
implicit strength	0	reliability	0
complexity	1	ease of repair	0
weight	5	speed	0
robustness	4	cost	0
no. of parts	4	structural efficiency	0
other equt needed	5	complexity	0
damage tolerance	1	deck obstruction	0

Concept: alignment connection	name: Barrel



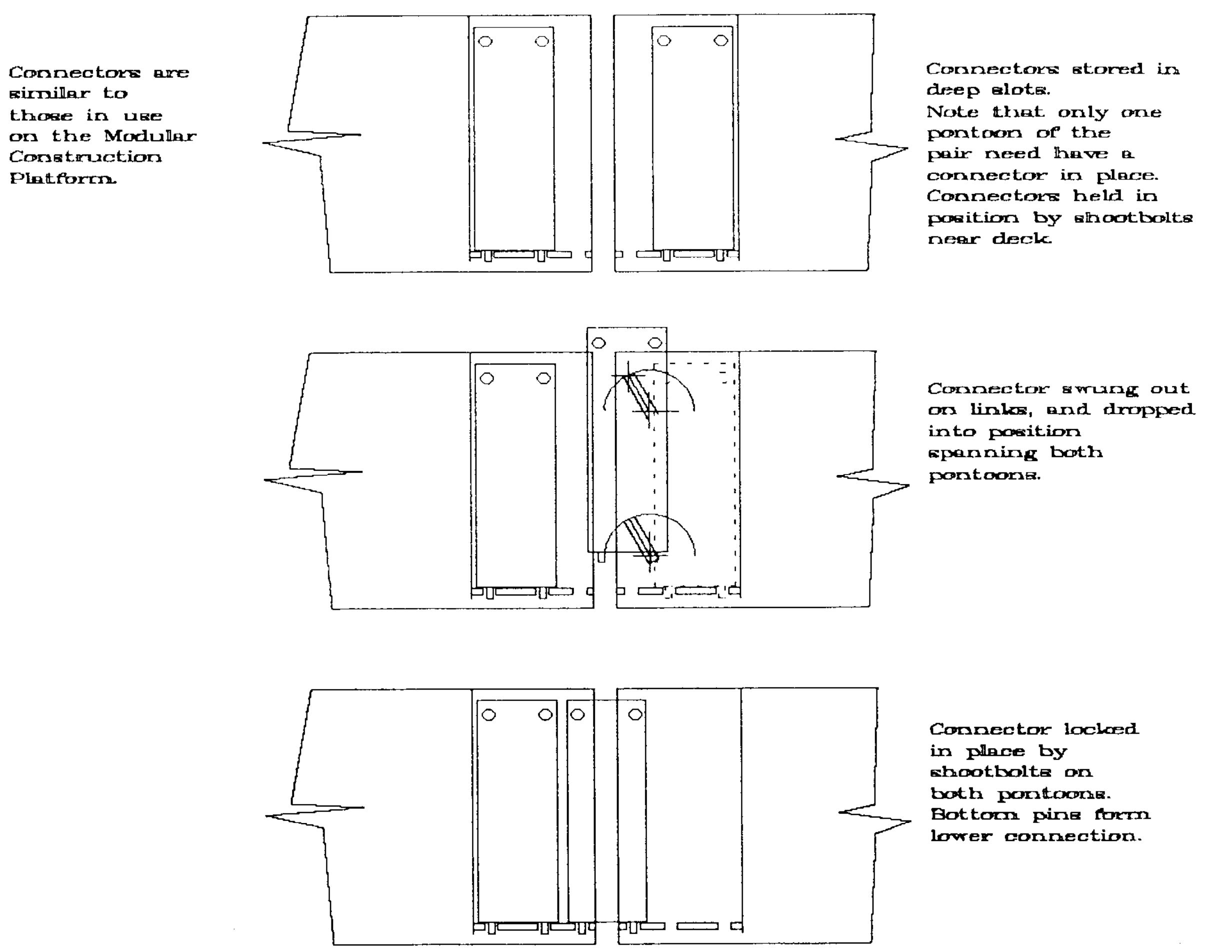
Modules are winched onto floating drum, which acts as centering guide.



Once located, system may be secured as pivot or locked as rigid connection.

safety	in use	3	deck openings	5
	hazard if fails	4	protrusions	4
reliability		4	configuration scope	2
cost		3	pontoon implications	2
ease of handling		3	Abilities as a connector:	
special equt. needed		3	maintainability	3
implicit strength		3	reliability	4
complexity		4	ease of repair	3
weight		3	speed	4
robustness		2	cost	3
no. of parts		4	structural efficiency	4
other equt needed		3	complexity	3
damage tolerance		2	deck obstruction	5

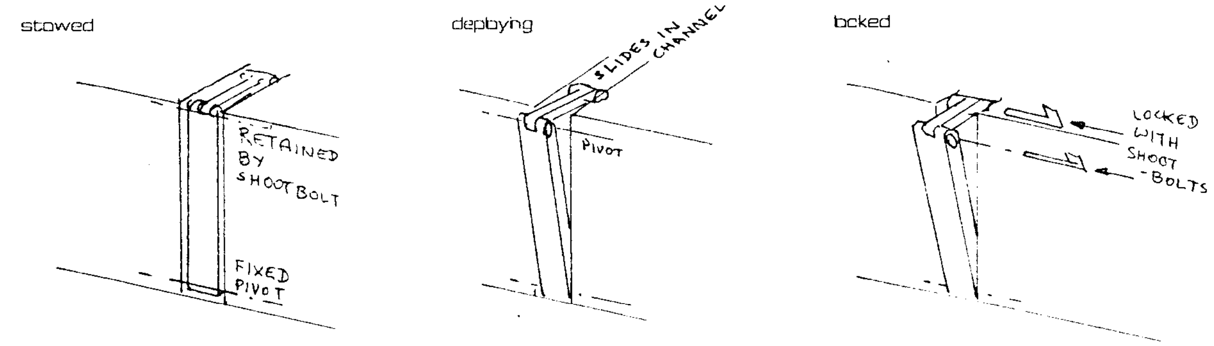
Concept: connection	name: Integral MEXE



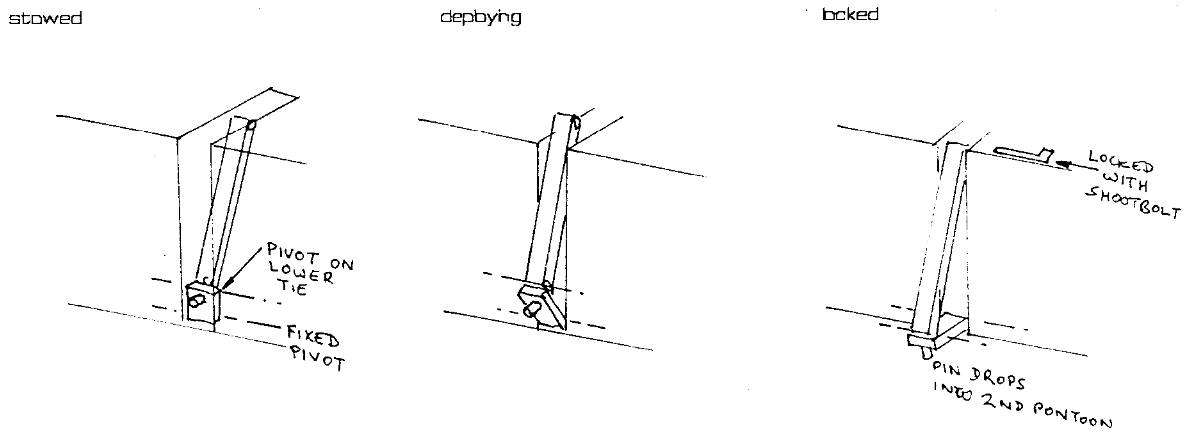
safety in use	4	deck openings	4
hazard if fails	5	protrusions	5
reliability	4	configuration scope	5
cost	4	pontoon implications	4
ease of handling	4	Abilities as a connector:	
special equt. needed	5	maintainability	4
implicit strength	5	reliability	4
complexity	4	ease of repair	5
weight	3	speed	5
robustness	4	cost	3
no. of parts	5	structural efficiency	5
other equt needed	5	complexity	4
damage tolerance	4	deck obstruction	5

Concept: connection	name: Extending truss

UPPER LINK



LOWER LINK



safety in use	4	deck openings	4
hazard if fails	5	protrusions	5
reliability	4	configuration scope	5
cost	5	pontoon implications	4
ease of handling	5	Abilities as a connector:	
special equt. needed	5	maintainability	3
implicit strength	4	reliability	4
complexity	4	ease of repair	2
weight	5	speed	5
robustness	4	cost	5
no. of parts	5	structural efficiency	5
other equt needed	5	complexity	4
damage tolerance	3	deck obstruction	5

Concept scoring

At the base of each concept sheet there is a scoring box covering a range of facets. These are intended as a first pass at identifying the various ideas' strengths and weaknesses and are based on a consensus of engineering judgement. Scores are always from 0 to 5; the higher the score the better. Bear in mind that these are initial scores only, which may well be modified in the course of the next phase of the project, as concepts are developed, and in the light of comments from potential users of the equipment.

The scoring categories are intended to reflect the following aspects:-

safety in use	self explanatory
safety: hazard if fails	the safety of the system in the event of a failure during system use
reliability	self explanatory
cost	self explanatory
ease of handling	self explanatory
special equipment needed	self explanatory
implicit strength	some systems will tend to use material in an effective way: load paths will be direct, loads will be well distributed etc. This structural aspect is reflected in this category.
complexity	self explanatory
weight	self explanatory
robustness	self explanatory
number of parts	an indication of the number of separate parts involved in the system
other equipment needed	the degree to which the system is likely to rely on external equipment, e.g. cranes.
damage tolerance	self explanatory
deck openings	some systems may require openings in the pontoon decks. Such openings will affect the strength of the pontoons, and hence tend to increase their weight.
protrusions	as noted in "Alignment & Connection", protrusions from the modules will be vulnerable to damage as the modules are brought together. This category reflects the vulnerability to this type of damage.
configuration scope	the degree to which the system can be used in configurations other than end-to-end connection, e.g. for side-to-side connection of modules.
pontoon implications	the influence that the system exerts on the pontoon form and structure.

Weighting of scores

As well as presenting the scores concept by concept, the figures from these scoring blocks have been extracted and are presented for all concepts in table 4.1 together with the totals for each concept. Since some of the ideas include scope for module connection as well as module alignment, a “facilities” score has been added. This is 1 for a concept which fulfils only one of the two functions, and 2 where a concept caters for both alignment and connection.

Table 4.2 expands on this scoring scheme. It is considered that some of the aspects tabulated for each concept are more important than others: for instance, basic safety is important whereas strength is something that can be engineered in. An attempt has been made, therefore, at assigning weighting factors to each aspect, as shown in table 4.2. These weighting factors can be multiplied by each concept’s scores to provided weighted totals for the concepts. The differentiation of single-facility and dual-facility concepts can again be applied.

Comments on scoring & weighting system

As noted above, the scores presented are initial ones based on a consensus of engineering judgement. In assessing the results of this exercise, the following points should be considered:

a the “facilities” scoring is somewhat simplistic. If two modules can be brought together and held together safely and effectively, their interconnection presents less of a problem. If may be desirable, therefore, to give “alignment” a higher score than “connection” rather than considering each as equally desirable.

b no score has been assigned for speed of operation. The importance of this factor is recognised but it was not considered that, at this stage, meaningful scores could be assigned to the concepts.

c the weighting factors used for safety, reliability etc. do not necessarily reflect the priorities of the potential operator. Feedback on these weighting factors will be useful for the next stage of the project.

Results of exercise

From this exercise it can be seen that, using the initial scoring and weighting systems used here, the weighted totals for the different concepts, before differentiating between those which allow only for alignment or connection and those which cater for both, range from 191 to 274. At this stage the highest five scores are respectively;

- **extended truss**
- **ramshorn**
- **integral mexe**
- **bias net**
- **inflatable link**

		CONCEPT														
		ramshorn	hupozoma	madonna	inflatable link	floating tramlines	pressurise tubes	bias net	folding ends	powered proboscis	cats cradle	SWATH docking station	floating dock	barrel	integral MEXE	extending truss
safety	in use	4	4	4	4	5	4	3	4	5	1	5	5	3	4	4
	hazard if fails	1	1	4	4	2	3	2	1	4	3	0	0	4	5	5
reliability		5	4	4	3	5	3	3	4	3	4	3	4	4	4	4
cost		5	5	4	3	4	3	5	3	2	5	0	1	3	4	5
ease of handling		5	3	3	4	4	3	3	3	3	2	5	5	3	4	5
special equipment needed		5	4	3	4	3	3	5	4	2	3	5	5	3	5	5
implicit strength		0	3	5	4	0	0	0	5	0	0	0	0	3	5	4
complexity		5	4	3	3	3	3	4	3	2	4	1	2	4	4	4
weight		5	4	3	3	4	4	5	3	2	4	5	0	3	3	5
robustness		5	4	5	4	4	3	4	4	3	4	4	5	2	4	4
number of parts		5	5	4	4	3	3	5	4	3	3	4	4	4	5	5
other equipment needed		5	4	3	4	2	3	5	4	3	4	5	0	3	5	5
damage tolerance		4	4	2	4	4	2	3	3	2	3	1	2	2	4	3
deck openings		5	5	4	4	5	5	5	5	5	5	5	5	5	4	4
protrusions		5	1	5	5	5	5	5	3	5	5	5	5	4	5	5
configuration scope		5	2	3	4	0	4	5	2	5	5	0	0	2	5	5
pontoon implications		5	3	2	2	4	5	5	2	5	5	5	5	2	4	4
TOTALS		74	60	61	63	57	56	67	57	54	60	53	48	54	74	76

	ramshorn	hupozoma	madonna	inflatable link	floating tramlines	pressurise tubes	bias net	folding ends	powered proboscis	cats cradle	SWATH docking station	floating dock	barrel	integral MEXE	extending truss
facilities	1	2	2	2	1	1	1	1	1	1	1	1	2	1	1
factored total	74	120	122	126	57	56	67	57	54	60	53	48	108	74	76

TABLE 4.1

		score weighting factor	CONCEPT														
			ramshorn	hupozoma	madonna	inflatable link	floating tramlines	pressurise tubes	bias net	folding ends	powered proboscis	cats cradle	SWATH docking station	floating dock	barrel	integral MEXE	extending truss
safety	in use	5	20	20	20	20	25	20	15	20	25	5	25	25	15	20	20
	hazard if fails	5	5	5	20	20	10	15	10	5	20	15	0	0	20	25	25
reliability		5	25	20	20	15	25	15	15	20	15	20	15	20	20	20	20
cost		2	10	10	8	6	8	6	10	6	4	10	0	2	6	8	10
ease of handling		4	20	12	12	16	16	12	12	12	12	8	20	20	12	16	20
special equipment needed		3	15	12	9	12	9	9	15	12	6	9	15	15	9	15	15
implicit strength		2	0	6	10	8	0	0	0	10	0	0	0	0	6	10	8
complexity		4	20	16	12	12	12	12	16	12	8	16	4	8	16	16	16
weight		3	15	12	9	9	12	12	15	9	6	12	15	0	9	9	15
robustness		4	20	16	20	16	16	12	16	16	12	16	16	20	8	16	16
number of parts		4	20	20	16	16	12	12	20	16	12	12	16	16	16	20	20
other equipment needed		3	15	12	9	12	6	9	15	12	9	12	15	0	9	15	15
damage tolerance		5	20	20	10	20	20	10	15	15	10	15	5	10	10	20	15
deck openings		3	15	15	12	12	15	15	15	15	15	15	15	15	15	12	12
protrusions		5	25	5	25	25	25	25	25	15	25	25	25	25	20	25	25
configuration scope		2	10	4	6	8	0	8	10	4	10	10	0	0	4	10	10
pontoon implications		3	15	9	6	6	12	15	15	6	15	15	15	15	6	12	12
TOTALS			270	214	224	233	223	207	239	205	204	215	201	191	201	269	274

	ramshorn	hupozoma	madonna	inflatable link	floating tramlines	pressurise tubes	bias net	folding ends	powered proboscis	cats cradle	SWATH docking station	floating dock	barrel	integral MEXE	extending truss
facilities	1	2	2	2	1	1	1	1	1	1	1	1	2	1	1
factored & weighted total	270	428	448	466	223	207	239	205	204	215	201	191	402	269	274

TABLE 4.2

After application of the facility factors, the order changes to

- **inflatable link**
- **madonna**
- **hupozoma**
- **barrel**
- **extending truss**

The notes under “Comments on scoring & weighting system” and the notes on the concept sketches must be borne in mind in examining these results.

Further Consideration

Having given further consideration to the table of scoring method of primary concept evaluation, it was concluded that the method had sufficient advantage over other possibilities to be retained as the basis for the next phase of the project. Further detailed consideration, however, revealed that whilst the simple scoring system yielded remarkably similar results when subjected to the different views, ideas, experience and background of individuals involved with the project, it was clear that the weighting factor applied by multiplication was far too coarse an approach. It was considered that a restricted number of further factors should be applied, again in a score-card form. Accepting that the same provisos apply to the original concept scoring arrangement, the additional factors were those believed to be important in consideration of any of the concepts with regard to the ability of that concept to act not only as a system to bring the modules together and locate them, but also to additionally act as the final connector. As with the initial review, each factor was scored from 0-5 with the scores from the connector assessment added to the initial review totals.

The factors considered were:-

1. Maintainability
2. Reliability
3. Ease of Repair
4. Speed
5. Cost
6. Structural Efficiency
7. Complexity
8. Deck Obstruction

The list is not presented in any order of importance. The description of the assessment topics is believed self-explanatory.

The revised method yielded a revised unweighed order of:-

- **extending truss & integral mexe**
- **madonna**
- **hupozoma**
- **inflatable link**
- **folding ends**

With weighting factors, this became:-

- **integral mexe**
- **extending truss**
- **madonna**
- **inflatable link**
- **hupozoma**

extension to tables:

abilities as a connector

	CONCEPT														
	ramshorn	hupozoma	madonna	inflatable link	floating tramlines	pressurised tubes	bias net	folding ends	powered proboscis	cats cradle	SWATH docking station	floating dock	barrel	integral MEXE	extending truss
maintainability	0	4	3	2	0	0	0	3	0	0	0	0	3	4	3
reliability	0	3	5	3	0	0	0	4	0	0	0	0	4	4	4
ease of repair	0	2	4	2	0	0	0	2	0	0	0	0	3	5	2
speed	0	4	5	3	0	0	0	4	0	0	0	0	4	5	5
cost	0	5	3	3	0	0	0	4	0	0	0	0	3	3	5
structural efficiency	0	2	5	3	0	0	0	3	0	0	0	0	4	5	5
complexity	0	4	3	3	0	0	0	3	0	0	0	0	3	4	4
deck obstruction	0	5	5	5	0	0	0	5	0	0	0	0	5	5	5
TOTALS	0	29	33	24	0	0	0	28	0	0	0	0	29	35	33
Totals from previous table	74	60	61	63	57	56	67	57	54	60	53	48	54	74	76
OVERALL TOTALS	74	89	94	87	57	56	67	85	54	60	53	48	83	109	109
	ramshorn	hupozoma	madonna	inflatable link	floating tramlines	pressurised tubes	bias net	folding ends	powered proboscis	cats cradle	SWATH docking station	floating dock	barrel	integral MEXE	extending truss

extension to tables:

abilities as a connector

	score weighting factor	ramshorn	hupozoma	madonna	inflatable link	floating tramlines	pressurised tubes	bias net	folding ends	powered proboscis	cats cradle	SWATH docking station	floating dock	barrel	integral MEXE	extending truss
		CONCEPT														
maintainability	3	0	12	9	6	0	0	0	9	0	0	0	0	9	12	9
reliability	4	0	12	20	12	0	0	0	16	0	0	0	0	16	16	16
ease of repair	5	0	10	20	10	0	0	0	10	0	0	0	0	15	25	10
speed	4	0	16	20	12	0	0	0	16	0	0	0	0	16	20	20
cost	3	0	15	9	9	0	0	0	12	0	0	0	0	9	9	15
structural efficiency	3	0	6	15	9	0	0	0	9	0	0	0	0	12	15	15
complexity	3	0	12	9	9	0	0	0	9	0	0	0	0	9	12	12
deck obstruction	5	0	25	25	25	0	0	0	25	0	0	0	0	25	25	25
TOTALS		0	108	127	92	0	0	0	106	0	0	0	0	111	134	122
Totals from previous table		270	214	224	233	223	207	239	205	204	215	201	191	201	269	274
OVERALL TOTALS		270	322	351	325	223	207	239	311	204	215	201	191	312	403	396
		ramshorn	hupozoma	madonna	inflatable link	floating tramlines	pressurised tubes	bias net	folding ends	powered proboscis	cats cradle	SWATH docking station	floating dock	barrel	integral MEXE	extending truss

CHAPTER 3

CHAPTER 3

STRENGTH ASPECTS

Naturally, stress and strength calculations for connectors can only be made with any realism once general mechanical and structural arrangements have been decided. However, load transmission through connectors will almost certainly involve several basic transmission mechanisms, e.g.:

transfer of bending moments via direct tension and compression loads;
shear transfer via diagonal tension/compression.

To indicate the likely member sizes involved in connector design, the load envelope of Chapter 2 has been applied to a selection of load transfer mechanisms.

Likely modes of load transfer are sketched in figure 5.1. Only the dominant loads - vertical shear and vertical bending - are explored: from Garrison's work these components are the most onerous. In any event it is likely that a connection scheme resisting these two components will have some inherent capacity for resisting the other four components.

The sizing of components clearly requires assumptions about safety factors, material grades etc. For this exercise, the following approach has been adopted:

mild steel has been assumed, with yield stress = 36,000 psi;

static design stresses only are considered - dynamics and fatigue behaviour will depend heavily on the structural and mechanical arrangements adopted;

sizes are calculated to give a nominal direct stress of 0.6 yield, and a nominal shear stress of 0.6 of the direct stress value, i.e. 0.36 yield;

local load concentrations, e.g. from a vehicle wheel adjacent to a connector, are not considered;

where a load transfer mechanism is invoked it is assumed to behave in a "pure" form: compression is pure compression with no bending coupling, shear pins work in pure shear without inducing bending stress etc.

The results of this exercise are set out in figure 5.2, which shows estimates of the material cross-section requirements: resulting values are shown for 2, 3 & 4 connectors across a single pontoon width; ideally, the load per connector would be directly proportional to the number of connectors. In practice however the distribution of load between connectors will be dependent on the stiffness of the pontoon structure and is likely to be highly uneven.

It must be borne in mind that this section deals only with the transfer of loads between modules: no account is taken of the diffusion of loads into the module body, which will clearly have strength implication for the system.

From this simple exercise, it can be seen that the amounts of structural material needed in the connection system are not excessive, even when additional safety factors are taken into account.

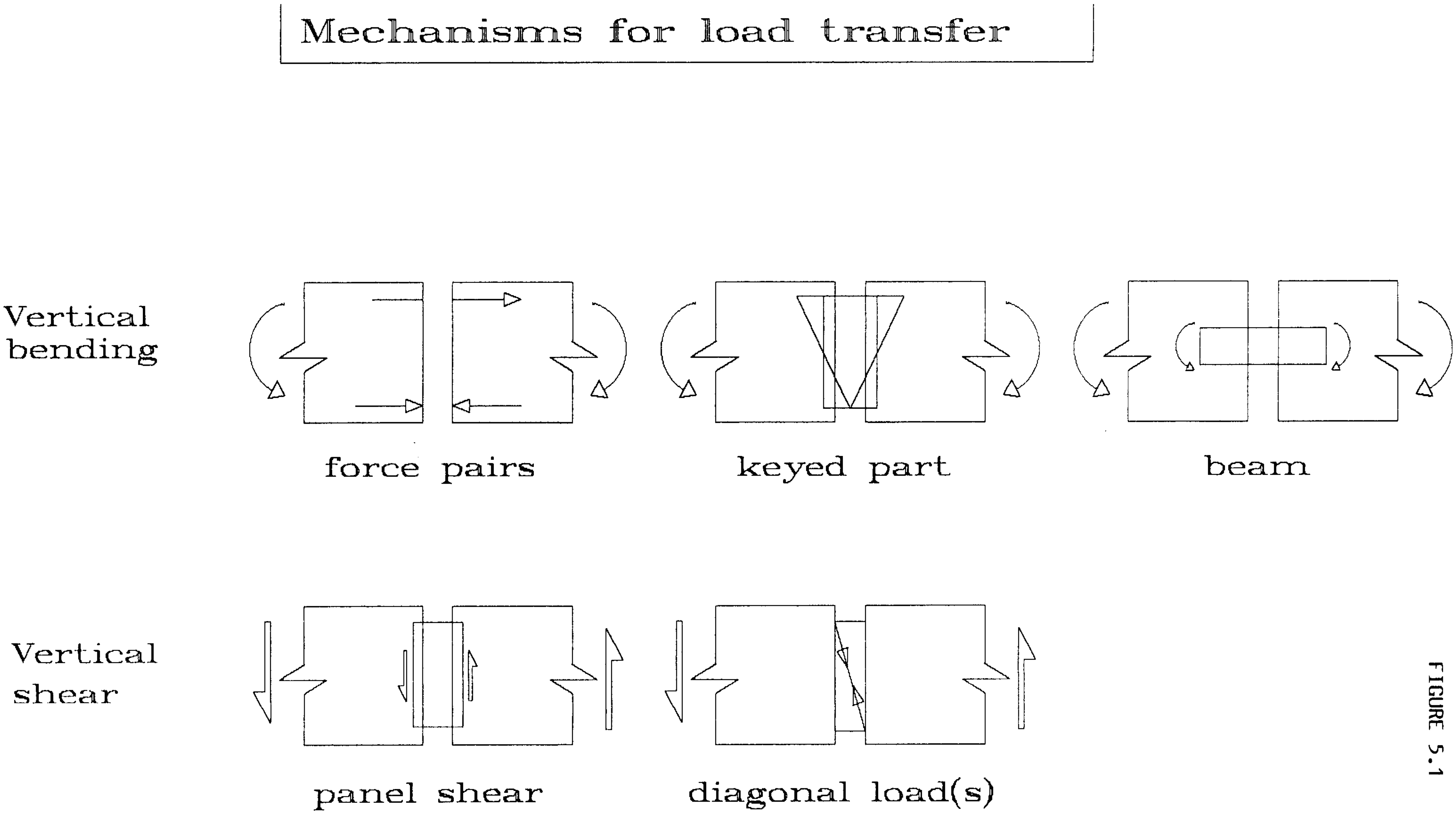

Mechanisms for load transfer
Vertical bending
force pairs
keyed part
beam
Vertical shear
panel shear
diagonal load(s)

FIGURE 5.1

FIGURE 5.2

Rough sizing for design loads

	connector across section	force pairs link CSA (in2)	keyed part	beam I (in4)	beam possible RHS
			not sized:		
vertical bending	2	8.3	dependen	57.9	18x6x0.31
	3	5.5	on design	38.6	16x4x0.31
	4	4.1	adopted	28.9	12x8x0.25

	connector across section	panel shear plate CSA (in2)	diagonal loads: Euler strut I (in4)	diagonal loads: Euler strut possible std pipe	diagonal loads: AISC std pipe
vertical shear	2	4.3	1.4	2.5 in	4 in
	3	2.8	0.91	2.5 in	3.5 in
	4	2.1	0.56	2.0 in	3 in

CHAPTER 4

CHAPTER 4

CONCLUSIONS

Although the original task was to assess suitability for further development systems of connection of relatively large modules for the purposes of forming ocean barges platforms etc., it became evident at an early stage in the work that whilst a wide variety of concepts could be used to join modules together with relative simplicity, low technology and adequate strength, the assessments of sea-keeping and relative motion of the module result in the situation where the bringing together of the modules and safely locating them securely in the manner that will allow connection to take place, presents the greatest challenge and should command the greater portion of this work and of further investigation and development.

As can be seen from some of the broad concepts that are put forward in this paper, there would appear to be many possible solutions, however, from the work carried out to date, to achieve a solution which is safe, practical, simple and universal in operation as well as cost effective, is likely to require considerable effort both in terms of theoretical and practical data and experience. In particular, we believe it most important that in-service experience, opinions and preferences of military operators of current pontoon and barge systems are obtained.

The probable in-service loading on any potential connector system is reliably predictable by a variety of mathematical methods, using both engineering and naval architecture base methods. Such factors as relative motion of separated modules etc. can be reliably predicted by theory and, if necessary, further verified by model experiment and simulation. It is foreseen, however, that difficulties will occur and it will be necessary to develop technology to simulate graphically and/or in model form the interaction between modules when brought into close proximity and to simulate the location and restraint of the modules to carry out the actual connection process using mechanical handling and man-power techniques. Once alignment and restraint is achieved, then assessment of the structural arrangements necessary both for modules and connectors can be made and detailed designs progressed using readily available current technology and without major effort.

It is believed that the assembly of relatively large modules into floating barges, causeways and many other floating structures, is undoubtedly possible and relatively simple from an engineering standpoint. The aim for future study should be to assess the more promising of the wide variety of possible options to achieve the bringing together and restraint of the modules to facilitate the connection and imposing as few operational and strategic constraints as possible.